Bioacoustic Absorption Spectroscopy

Dr. Orest Diachok
University of Washington, Applied Physics Laboratory
and
Poseidon Sound
telephone: 703 716 1241 e-mail: OrestDia@aol.com
and
Russell Light
University of Washington, Applied Physics Laboratory

Document number: N000140410441

LONG TERM GOAL

Demonstrate the potential of bioacoustic absorption spectroscopy for tomographic mapping of the bioacoustic parameters of fish with swim bladders.

OBJECTIVES

Develop robust instruments, measurement procedures, data processing methods, displays, and analytical methods for extracting bio-acoustic parameters, viz., number density, and depth and thickness of fish layers vs. fish length (and possibly species) from broadband transmission loss (TL) measurements at frequencies between 10 Hz and 10 kHz.

APPROACH

Analyze data derived from bio-acoustic absorption spectroscopy experiments in the Santa Barbara Channel (BAS II), which were conducted in co-operation with fisheries biologists from the Southwest Fisheries Science Center. These experiments employed a unique, broadband (250 Hz - 10 kHz), light weight, long term, autonomous source, and state of the art receiving arrays, which were specifically designed for BAS experiments. Apply propagation model, which accounts for the effects of bio-absorptivity on TL, to bio-acoustic absorptivity measurements, and derive bio-acoustic parameters of sardines and anchovies and other fish. Formulate methods for classification of absorption and scintillation lines due to fish with swim bladders, and frequency down-shifted lines due to schools ("bubble cloud") resonances.

Investigate consistency of estimated bio-acoustic parameters with trawling and echo sounder data recorded during BAS II, and geo-acoustic parameters which were derived from coincident "chirp" sonar and core data.

WORK COMPLETED:

During this reporting period the analysis and documentation of BAS II bio-absorptivity data was completed, and a manuscript was submitted to the Journal of the Acoustical Society of America. The main lessons learned will be summarized in this report. The scintillation index associated with fish dynamics was also investigated and an *invited* paper on this topic was published in the Proceedings of the International Conference on Acoustic Technologies and Results.

BAS II was conducted in the Santa Barbara Channel in August 2002. The array was 45 m long and consisted of 16 elements with an inter-element spacing of 3 m. The source depth was 9 m. The separation between the source and array was 3.7 km, and the water depth was 63 m. The array was deployed at depths between 8 and 53 m. The geometrical configuration of this experiment is illustrated in Figure 1.

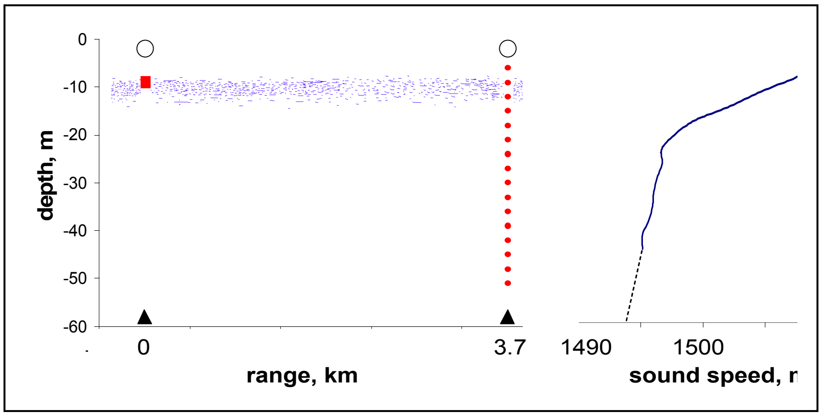

Figure 1. Experimental geometry (left) and representative sound speed measurements.

The source transmitted a sequence of 65 five sec long tones at frequencies between 250 Hz and 10 kHz. This permitted calculation of average received intensity (i), TL, standard deviation (sd), signal to noise ratio and scintillation index, si (defined as sd/i) as a function of frequency and depth. This report will focus on bio-absorptivity.

Trawls provided estimates of the modal lengths of year classes of sardines and anchovies. A scientific echo sounder provided information on depth distributions of biological scattering layers.

A set of three orthogonal thermistor strings which were spaced 2 km apart, recorded temperature data throughout this experiment, and provided information about sound speed profiles, stochastic internal waves and tidally induced solitons. There were no solitons during the 2 hour measurement periods during night and day, which were analyzed for bioacoustic parameters. Only nighttime data will be reported here.

Geo-acoustic parameters of the top few meters along the entire measurement track were derived from cores and "chirp" sonar.

RESULTS

Lessons learned from BAS II:

Lesson 1: The resonance frequencies of absorption lines and trawl data were generally consistent with trawling data; however *there were important exceptions which illustrate the strength of the BAS method and the limitations of trawling data*. The frequencies of absorption lines were consistent with resonance frequencies calculated from modal lengths derived from trawl data for adult sardines and anchovies, and for juvenile anchovies, but not for juvenile sardines. In particular, trawls provided no evidence of juvenile sardines, whereas BAS data indicated that juvenile sardines were plentiful. It is noteworthy that BAS observations were consistent with historical data.

There was also an inconsistency between trawl and BAS estimates of the relative numbers of adult anchovies and sardines. Trawl data indicated that there were many more adult anchovies than sardines, whereas BAS data suggested that adult sardines were much more plentiful. This discrepancy was probably caused by *species and year class dependent "avoidance bias" and "mesh size bias"* inherent in trawl measurements. In particular, sardines are known to be adept at avoiding trawl nets, whereas anchovies are readily caught by trawl nets (Gerlotto, personal communication).

These observations suggest that *BAS measurements could be used effectively to complement trawl data.* In particular trawl (together with historical) data could be used to determine the presence and dominant lengths of species, and to facilitate classification of absorption lines, whereas concurrent BAS measurements could be employed to determine number densities.

Lesson 2: Sound propagation is sufficiently deterministic, i.e. not affected by internal waves, at ranges less than about 4 km and frequencies below about 2 kHz to permit accurate estimation of number densities; whereas sound propagation at higher frequencies and longer ranges is confounded by this effect. This range/frequency limitation is an important consideration in the design of practical BAS based monitoring systems.

Results of BAS II: Figure 2a shows echo sounder measurements of the depth of fish scattering layers at night; Figures 2b and c show transmission loss vs. depth and frequency at night. The frequencies of absorption lines at approximately 1.1, 2.1 and 4 kHz at approximately 13 m are consistent with the presence of 15 cm long sardines and 10 and 6 cm long anchovies respectively. The depths at which absorption lines and integrated back-scattering strengths are maximum are approximately the same, viz., about 13 m. The average depth of the maxima (~13 m) is consistent with the average depth of biological scattering layer (~13 m), which was determined from echo sounder measurements, as illustrated in Figure 2a.

The absorption lines at 1.1, 2.4 kHz, which are evident in Figure 2b and c, are consistent with 15.5 and 8 cm long sardines at 13 m, whereas the absorption lines at 1.5 and 4 kHz are consistent with 11 and 5.5 cm long anchovies at 13 m. The lines at 1.1 kHz (15.5 sardines), 1.5 kHz (11 cm anchovies) and 4 kHz (5.5 cm anchovies) are consistent with the trawl data, whereas the line at 2.4 kHz (8 cm sardines) was not "confirmed" by trawl data, but is consistent with historical data in the Santa Barbara Channel. The line at 1.9 KHz is probably due to anchovies or sardines, which are approximately 9.5 cm long.

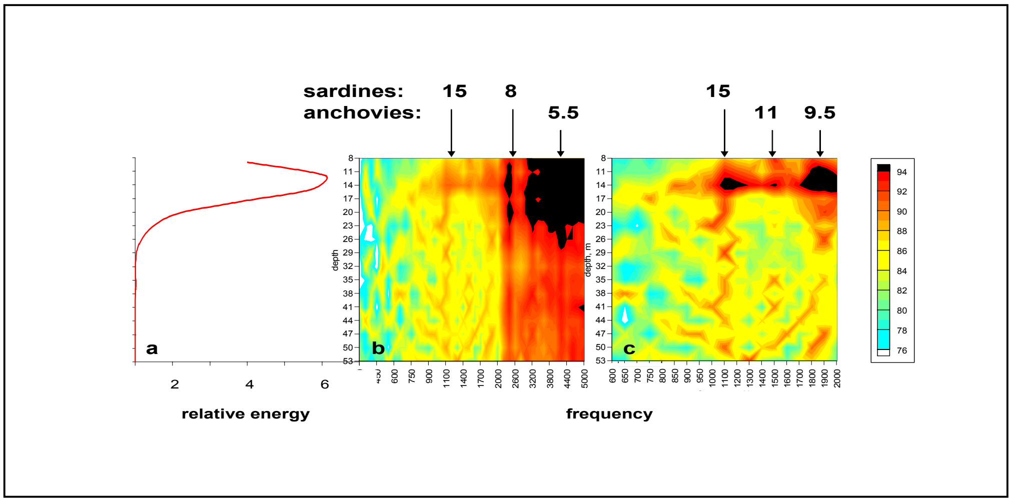

Figure 2. a: Backscattered energy vs. depth derived from echo sounder data; b: TL vs. depth and frequency between 300 Hz and 5 kHz; and c: TL vs. depth and frequency between 600 Hz and 2 kHz. Note change in scale in Figure c. Arrows correspond to calculated resonance frequencies associated with sardines and anchovies of length, L.

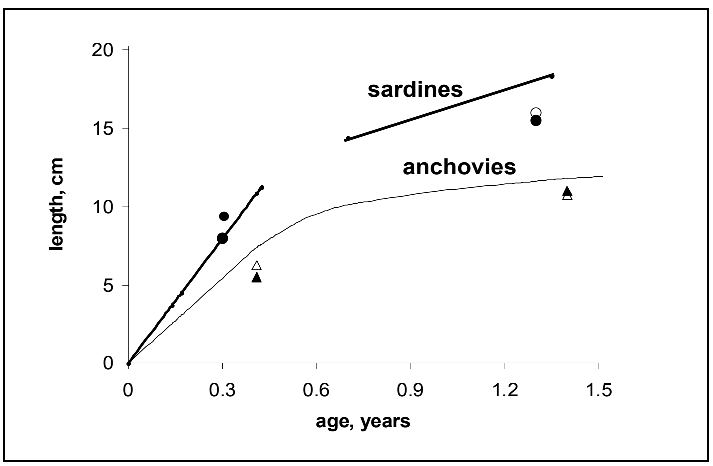

Figure 3. Standard length of sardines and anchovies derived from trawls of sardines (O) and anchovies (□), BAS measurements of sardines (●) and anchovies (▲), and historical data. Trawls provided no evidence of the presence of juvenile sardines.

An inversion algorithm, which permits concurrent estimation of bio-acoustic parameters of fish with swim bladders and geo-acoustic parameters of the bottom from TL measurements, was applied to BAS II data. The inversion is based on minimizing the rms difference, Δ, between measured and calculated values of TL at all ranges and depths, and involved a simultaneous search for biological layer depth, layer thickness and bio-absorption coefficient, and geo-sound speed, sound speed gradient and geo-alpha, as illustrated in Figure 4. Inversions are generally considered “acceptable”, and inverted results are probably meaningful, when $\Delta < 3$ dB.

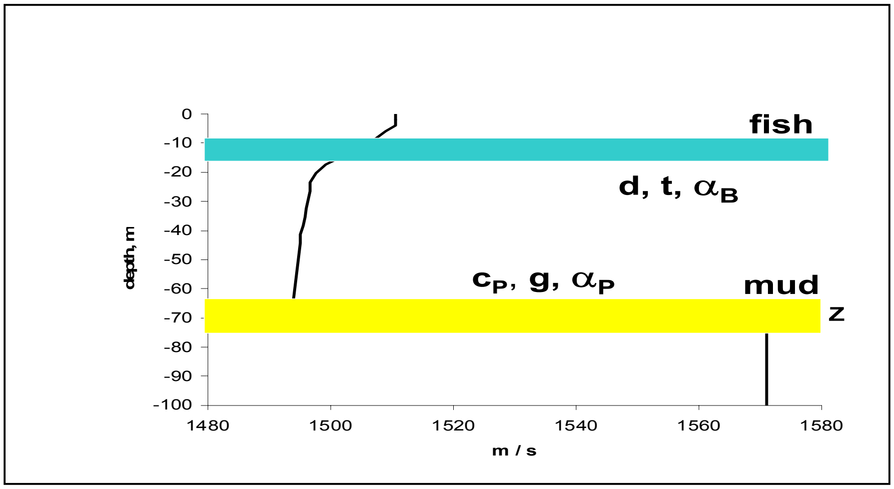

Figure 4. Bio and geo-acoustic models and associated parameters.

Inverted bioacoustic parameters were consistent with coincident echo-sounder and trawling data; and inverted geoacoustic parameters were consistent with "chirp" sonar measurements of these parameters. The resultant best fit to the TL data at 1.1 kHz is shown in Figure 5. Also shown is the depth of the biological absorption layer. Measurements of TL loss are highest in the vicinity of the absorption layer, in agreement with theoretical calculations. The magnitude of Δ at 1.1 kHz was 1.8 dB, suggesting that the assumption that propagation could be modeled with a deterministic code was justified at this frequency and range. The magnitude of Δ at 1.9 kHz was 3 dB, suggesting that propagation was probably confounded by stochastic mode coupling at frequencies above 1.9 kHz at this range.

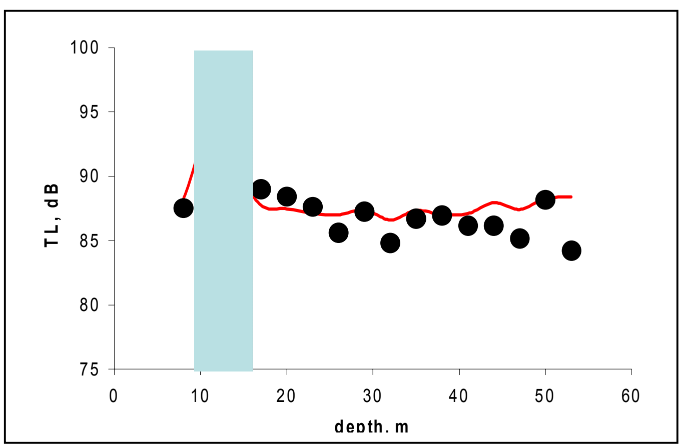

Figure 5. Calculations and measurements of TL at 1.1 kHz, and location of fish layer.

Implications for experimental design and sampling strategy: During this reporting period we considered several changes in experimental designs and sampling strategy to maximize biological information content and minimize the effects of internal waves on propagation, the cost and complexity of conducting BAS experiments, and the cost and complexity of data interpretation.

We decided to conduct future experiments at shorter ranges (< 1 km) to minimize the effects of internal waves at high frequencies.

We also considered sampling the acoustic field with a "bioacoustic probe" attached to a "glider". This sampling strategy would have permitted sampling of the biological field in three dimensions, which seemed highly attractive to fisheries biologists, but appeared to be too complicated, too risky and too expensive to program managers, and was not supported.

Ultimately it became clear that the biological information content could be maximized, and the cost, complexity and risk could be minimized by conducting BAS measurements concurrently with echo sounder measurements in the *vertical* direction. Unpublished calculations suggest that vertical BAS measurements will result in *unbiased* estimates of number densities vs. length and possibly species over a very broad frequency range of interest, possibly as high as 7 kHz...at relatively low cost. Furthermore, interpretation of vertical BAS measurements will be extremely simple…over the entire frequency range, as it will not be affected by sound speed profiles, geo-acoustic parameters, internal waves and solitons, *in sharp contrast* to horizontal BAS measurements, which are complicated by all of these effects. Results of these simulations will be documented elsewhere.

IMPACT / APPLICATIONS

Naval applications: This research suggests that the detection range of tactical sonars operating at/near the resonance frequencies of pelagic fish may be significantly reduced when operating in littoral environments, where concentrations of pelagic fish with swim bladders are large, such as the shallow seas off the coasts of the United States, China and the Arabian Sea. Combatants in littoral environments, where fish concentrations are high, may find themselves in situations where the detection range of one combatant's sonar, operating at the resonance frequency of a pelagic species, may be very short, whereas the opponent's sonar, operating at a different frequency, may be very long *at the same time*.

This research also indicates that operational codes, which are designed to invert geo-acoustic parameters from TL data, *must* consider the effects of bio-absorptivity in littoral regions where fish concentrations are high.

Fisheries applications: These results suggest that bio-acoustic absorptivity can be used to derive unbiased estimates of number densities vs. length (and possibly species) of fish with swim bladders.

TRANSITIONS

As a result of this research and my briefings for Naval Oceanographic Office (NOO) scientists, the head of the NOO Geoacoustics Program, Mr. David Harvey, decided that "development of algorithms for inversion of geo-acoustic parameters in the presence of bio-absorptivity" is a Navy *requirement*.

RELATED PROJECTS

Office of Naval Research (ONR) programs concerned with resonance back-scattering from fish at low frequencies, geo-acoustic inversion with "chirp" sonars, and internal wave induced "scintillation" in littoral environments; National Marine Fisheries Service (NMFS) biological sampling and fisheries sonar programs.

PUBLICATIONS

Papers in refereed journals and books

Diachok, O., S. Wales, P. Smith, C. Scalabrin and A. Turgut, **"**Estimation of bio- and geo-acoustic parameters from transmission loss data in a well calibrated environment", *submitted* to the J. Acoust. Soc. Am.

Orest Diachok, "Bioacoustic Absorption Spectroscopy: a new approach to estimation of the number and lengths of fish in the ocean", *Invited*, Chapter 14 in *Sounds in the Sea: from Ocean Acoustics to Acoustical Oceanography*, H. Medwin, Editor, Cambridge University Press, 2005.

Orest Diachok and Stephen Wales, "Concurrent inversion of bio and geo-acoustic parameters from transmission loss measurements in the Yellow Sea", J. Acoust Soc. Am., 2005.

Orest Diachok and Stephen Wales, "Effects of bioacoustic absorptivity on transmission loss in the Yellow Sea", US Navy Journal of Underwater Acoustics (*Invited*), July 2004.

Orest Diachok, Bernard Liorzou and Carla Scalabrin, "Estimation of the number density of fish from resonance absorptivity and echo sounder data", ICES J. Mar. Sci., 58, 137-153, 2001.

Orest Diachok, "Bioacoustic absorption spectroscopy: estimation of the biomass of fish with swim bladders", Bioacoustics, 12, 271-274, 2002, and an *Invited* talk presented at the International Conference on Fish Bioacoustics, Chicago, Ill., 2001.

Orest Diachok, "Interpretation of the spectra of energy scattered by dispersed anchovies", J. Acoust. Soc. Am., 110, 2917-2923, 2001.

Orest Diachok, "Absorption spectroscopy: a new approach to estimation of biomass" *(Invited),* Fisheries Research, 47, 231-244, 2000.

Orest Diachok, "Effects of absorptivity due to fish on transmission loss in shallow water", J. Acoust. Soc. Am., 105, 2107-2128, 1999.

Proceedings of conferences / abstracts

Orest Diachok, "Bioacoustic Absorption Spectroscopy: the promise of classification by fish size and species", *Invited*, Proceedings of the 150th Meeting of the Acoustical Society of America, J. Acoust. Soc. Am., 118, 1907, 2005.

Diachok, O., "Contribution of fish with swim bladders" to scintillation of transmitted signals", *Invited*, in Proceedings of the 1st International Conference on Underwater Acoustic Technologies and Results", J. Papadakis and L. Bjorno, Editors, IACM-FORTH, Heraklion, Greece, 2005.

Orest Diachok, “Effects of fish swim bladders on absorptivity and scintillation”, J. Acoust. Soc. Am., 116, 15, 2004.

Orest Diachok, Stephen Wales, George Cavanagh and Paul Smith, “Bioacoustic absorption spectroscopy (BAS): instruments, measurement strategies and results of experiments”, Proceedings of the IEEE Oceans Conference, 2003.

Orest Diachok, “Sound absorption due to fish: from David Weston’s discoveries to recent developments”, *Invited*, Proceedings of the Fall Meeting of the Acoustical Society of America, 2002.

Orest Diachok, “Observations of frequency shift associated with schooling fish”, Proceedings of the Spring Meeting of the Acoustical Society of America, 2003.

Jeff Dunne, Orest Diachok and Stephen Wales, “Observations of solitons in the Santa Barbara Channel”, Proceedings of the Spring Meeting of the Acoustical Society of America, 2003.

Orest Diachok and Stephen Wales, “Simultaneous inversion of geo and bio-acoustic parameters from transmission loss measurements in the Yellow Sea”, Proceedings of the Spring Meeting of the Acoustical Society of America, 2003.

PATENTS

I have been awarded a patent for the “bioacoustic absorption spectroscopy” method